Introduction

Caroline M. Isaacs

The Twelfth Annual PACLIM Workshop was held at the Asilomar Conference Center on May 2-5, 1995. The workshop included 32 talks and 26 posters presentations. The talks consisted of a 1-day theme session of nine 45-minute talks and two featured evening talks (Appendix A). Throughout the remainder of the meeting were over 20 shorter 20-minute presentations. Poster presenters gave a 1-2 minute introduction to their posters, which were displayed during the entire meeting (Appendix B). About 100 participants were registered at the workshop (Appendix C).

In this Proceedings volume, talks and posters have been combined and grouped by broad categories of subject matter — Theme Session on Interdecadal Climate Variability, Ocean/Atmosphere System, Fisheries, Hydrology, Hazards, Glaciers, Proxy Calibration, Pollen and Lake Records, and Time-Series Compilations. All presenters were invited to expand their abstracts into a manuscript for inclusion in the Proceedings volume, and all presentations (except Pulwarty's) are included in manuscript or abstract form. In addition to this year's Proceedings volume, the theme session is being prepared separately for journal publication.

Interdecadal Climate Variability

As previous PACLIM workshops have detailed for some years, climate variability is expressed at many time scales — from daily variations to millennial and longer changes. One scale especially important to societal and scientific concerns is decadal-scale variability. Regimes lasting several years to decades are widely observed in the climate record — and, because of their persistence, may have broad impact on natural systems (Swetnam and Betancourt, this volume). Famine-producing droughts, persistent "abnormal" flooding, high or low snowpacks, major changes in fish and other ecosystems all occur at a decadal scale. The Dust Bowl of the 1930s and the California drought of the 1980s are two examples from the recent historical record. Increasing resolution and spatial coverage of paleoclimate by proxy records shows that decadal-scale variability has been a persistent feature of the climate system for millennia (*eg*, Thompson and Mosley-Thompson 1989; Thompson 1991). For the scientist, interdecadal variability also introduces a "wild card" in trend analysis. Because most instrumental records cover no more than 100 years, and many records just a decade or so, interdecadal variability makes deciphering long-term trends often problematic. The 1976 step-like change in Pacific climate (Ebbesmeyer *et al* 1991) and similar "regime shifts" (*eg*,

Schimmelmann and Tegner 1992; Schwing 1994) are examples of interdecadal climate variability that can confound simple trend analysis.

What are the characteristics and causes of decadal-scale climate variability? At the 1995 PACLIM workshop, simulations of interdecadal changes in the ocean/atmosphere system explore a variety of important mechanisms and feedback scenarios. **Graham** (this volume) addresses the apparent rise in global average tropospheric temperatures over the last century and the apparent sharp rise since the mid-1970s. Using model simulation, Graham attributes the rise to enhancement of the tropical hydrologic cycle — principally an increase in the flux of moisture through the cycle — driven by increasing tropical ocean temperatures.

Miller *et al* (this volume) focus on upper-ocean temperature in the North Pacific, modeling the thermal and velocity fields over a two-decade period as forced by monthly "observed" total surface heat flux anomalies and wind stress anomalies. This simulation reproduces prominent North Pacific thermal anomalies at monthly to decadal time scales, providing some justification that such models can be used to explain the underlying physics and to "fill in" characteristics of the ocean variability that are not adequately observed. Miller *et al* also discuss maintenance of climate regimes through ocean dynamics, such as re-emerging wintertime SST anomalies surviving beneath the shallow summer mixed layer.

One of the most obvious candidates for climate forcing at an interdecadal scale is solar irradiance, which has a well known 11-year cycle superimposed on many other scales of variability. **Lean** (this volume) reviews current knowledge of the amplitudes and time scales of variability in solar radiative output available from contemporary monitoring and historical reconstructions. From the high correlation (0.86) between decadal mean reconstructed solar irradiance and decadal mean Northern Hemisphere surface temperature anomalies, Lean concludes that solar influences were predominant on decadal-scale climate variations during the pre-industrial period, 1610-1800.

Hydrologic and ecosystem responses to interdecadal ocean/atmosphere variability may be rather complex. **Francis *et al*** (this volume) point out that linkages between physical conditions and biological responses in the ocean often differ across time and space scales, and present knowledge contains only hints of the mechanisms of interaction. Although hydrologic responses also vary temporally and spatially, **Cayan *et al*** (this volume) show that precipitation, snowpack, and streamflow records reveal mutually consistent decadal-scale fluctuations over regional spatial scales (about 1000 kilometers). This decadal-scale hydrological variability has its roots in low-frequency fluctuations in atmospheric circulation. Some evidence suggests, however, that both hydrological and atmospheric circulation fluctuations may be associated with Pacific

Basin scale (and larger) anomaly patterns in sea surface temperature. Interestingly, the decadal SST anomaly patterns are spatially very similar to patterns that occur on ENSO time scales.

In terrestrial ecosystems, decadal scale climatic shifts have broadscale impacts. Examples include the drought of the 1930s in the Great Plains — the well-known Dust Bowl — and the drought of the 1950s in the southwestern United States, which culminated in widespread vegetation dieoff (**Swetnam and Betancourt**, this volume). Such episodes raise questions about the scale and amplitude of natural variability in comparison to anthropogenic influences, emphasizing the increasing importance of high-resolution proxies to determine natural ranges of variability for ecosystem management (Swetnam and Betancourt, this volume).

Two presentations discuss proxy time series at an interdecadal scale. **Baumgartner and Dunbar** (this volume) compare paleorecords of oxygen isotopes in coral bands at subannual resolution from the Galapagos Islands and fish scale abundance in varved sediment at 5-year resolution from the Santa Barbara Basin. Both records show spectral peaks at 17 years, 30 years, and 50 years, but each cycle length occurs in a distinct epoch — the 50-year cycle in the period 1670-1750 AD, the 33-year cycle in the period 1750-1850, and the 17-year cycle in the period 1860-1925. **Hughes** (this volume) reviews the wealth of natural records in western North America for studying interdecadal climate variability. Emphasis is on sub-continental tree-ring networks yielding spatial distribution of summer temperatures and winter half-year precipitation over the past 300-400 years.

In a synthesis of the dynamics and predictability of decadal climate variability, **Latif and Barnett** (this volume) describe a state-of-the-art coupled ocean/atmosphere general circulation model supporting the thesis that decadal variability over the North Pacific and North America is based on a cycle involving an organized pattern of ocean/atmosphere interactions over the North Pacific. The cycle, with a period of a few decades, involves the subtropical ocean gyre and the Aleutian low, the two major circulation fixtures in the North Pacific ocean/atmosphere system. Knowledge of such a cycle would provide a powerful tool for climate forecasting several years ahead over North America.

Ocean/Atmosphere System

A series of contributions discuss important aspects of variability in the ocean/atmosphere system at interdecadal and shorter scales. The first two papers examine spatial variability in long-term trends. Applying state-space statistical models to time series of wind stress and sea

surface temperature from the California Current (22°-48°N) for 1946-1990, **Schwing *et al*** (this volume) show that trends are not coherent between different regions along this coastal domain. The distinct latitudinal regionalization and cross-shelf variability has important implications for ecosystems studies as well as fisheries management and illustrates the value of evaluating the entire spectrum of temporal and spatial variability in climate research.

In the same area, **Parker** (this volume) examines 49-year time series of monthly mean upwelling indices along the North American coast during 1946-1994. Significant changes in the seasonal cycle of upwelling are apparent at interannual to decadal scales, but these changes are manifested quite differently at the three locations examined (57°N, 39°N, and 21°N). The most notable change is a sharp increase in spring upwelling at 21°N since the summer of 1976, apparently the result of relatively small shifts in atmospheric pressure gradients.

Cayan *et al* (this volume) examine instrumental records of the ocean/atmosphere system in the North Pacific for decadal-scale variability. The primary mode identified resembles a low frequency PNA pattern, involving strengthening and weakening of the Aleutian Low with cool anomalies in the central/western North Pacific mid-latitudes and warm anomalies in tropics/subtropics and along the eastern boundary — alternating to opposite phase after about 12 years. Decadal variations beyond the North Pacific are also discussed, and possible mechanisms — including ocean/atmosphere feedback — are considered.

Also in the North Pacific, **Holets** (this volume) compares wintertime polar-front jet stream positions during El Niño events before and after the 1975-1976 step-like change in SST. Although the wintertime jet stream patterns were similar across the North Pacific during El Niños within the two time periods, composites of the two jet stream patterns show a change in position, suggesting an interdecadal shift with implications for California rainfall.

Interdecadal changes in equatorial Pacific trade winds are analyzed by **Clarke and Lebedeva** (this volume). Using surface pressure difference as a proxy for zonally integrated wind stress, they suggest that equatorial trade winds have varied on decadal scales throughout the century — strengthening during the 1920s and 1930s, weakening from the mid-1940s to late 1950s, strengthening during the 1960s, and weakening rapidly since. Comparison with eastern Pacific sea surface temperature proxy records from corals suggests that similar oscillations extend back at least to 1600 AD.

According to **Mantua and Graham** (this volume), upper ocean temperature records from the tropical Pacific show broad-scale warming in the two periods 1976-1983 and 1990-1994. Numerous other climatic

indices — including upper ocean temperature records, the Southern Oscillation Index, central Pacific precipitation, and surface windstress across the equatorial Pacific — exhibit multi-year variability that is physically coherent with the upper ocean records, showing the system-wide scale of the warmings.

Analyzing more than 40 years of instrumental climate records on Niwot Ridge in the Colorado Rockies, **Losleben** (this volume) concludes that long-term trends show no significant changes in annual temperature averages but a long-term trend of decreasing fall temperatures and, at high elevation, increased precipitation. A notable feature of the record is the 1981-1985 "cold event", with annual temperature averages 3°C colder than in the rest of the record.

Turning to the influence of large-scale atmospheric circulation on regional climate, **Woodhouse** (this volume) focuses on winters of the Sonoran Desert. Based on principal component analysis of wintertime climate (the number of rainy days and average maximum temperatures) at 50 stations with six circulation indices (Southern Oscillation, equatorial Pacific sea surface temperature, modified Pacific North American, cyclone frequency, southwestern trough, and Pacific high/southwestern low), two components are identified that explain a significant amount of the climate variation. The two patterns can be described as a "typical" ENSO/positive PNA-type pattern, and a reverse PNA-type pattern characterized by a trough over the southwestern United States.

Also looking at climate characterization, **Craig *et al*** (this volume) explore moisture-driven modulations of the annual temperature cycle by examining the lag between insolation and maximum daily temperature at 252 stations in the western United States for 1961-1990. Results show that largest lags are in maritime settings and smallest lags are in semiarid regions. Interannual variations related to El Niño/La Niña also show the influence of moisture entrained by the jet stream.

Keeling and Whorf (this volume) discuss decadal patterns in atmospheric CO_2 as indicators of changing growth and decay of terrestrial vegetation. After adjustment for combustion of fossil fuels, residual trends of atmospheric CO_2 show a relationship to decadal-scale variations in surface air temperature, and new evaluation suggests that residual trends may also reflect seasonal variations. Because the amplitude of the seasonal cycle in atmospheric CO_2 measures the large-scale metabolic activity of land plants, changes in these relationships allow estimate of the fraction of CO_2 sequestered in the terrestrial biosphere during especially warm periods.

Fisheries and Biological Communities

Fisheries, and the character and complexity of linkages between climate and marine ecosystems, are addressed by a series of workshop presentations. **Greenland** (this volume) discusses the interrelationship between Coho salmon population offshore the Pacific Northwest and large-scale atmospheric events. Greenland identifies relationships at two time scales: (1) a 3-7 year variation related to the El Niño/Southern Oscillation, associated with warmwater anomalies and depressed salmon catches; and (2) a postulated 20-year variation related to Subarctic Current modes, with depressed salmon catches associated with strong water movement into the Alaskan gyre and enhanced salmon catches associated with strong water movement into the California Current. At lower latitudes, decadal-scale variations are also noted in the trans-Pacific migration of northern bluefin tuna (**Polovina**, this volume). Because the bluefin spawns only in the western Pacific, the proportion of juveniles migrating to the eastern Pacific determines the stock in that area. Decadal-scale variations in eastern Pacific abundance are apparently related to the distribution of the Japanese sardine, a key bluefin prey.

Paul Smith (this volume) overviews modeling environmental influences on the population dynamics of the common fishes. For chronic influences — seasonal, interannual, decadal, and centennial influences — fisheries models can now fairly successfully describe and predict population dynamics, requiring input of precise information at low time resolution. By contrast, fisheries models have difficulty predicting the effect of catastrophic influences — such as massive expatriation due to rapid transport of large surface volumes — and successful monitoring and predictive modeling would require information that, although cruder, was available at higher time resolution.

Spatial and temporal variability in zooplankton is detailed by **Mackas** (this volume) who examines 10-year time series of both zooplankton biomass and species composition at multiple sample locations off the British Columbia coast. An interesting feature of his results is the marked interannual anomalies in species composition lasting 0.3-5 years. Though not notably stronger in El Niño years, the anomalies are apparently coupled to longer-term changes in North Pacific ocean/atmosphere conditions since 1988. Reviewing a 23-year time series of physical and environmental variables in the San Francisco Bay estuary, **Lehman** (this volume) characterizes conditions associated with wet, normal, dry, and critical water year types. Results show that the biological community (phytoplankton chlorophyll *a* concentration and community composition) varied significantly more than did environmental conditions.

In the intertidal zone, a resurvey of invertebrate species — in a transect originally surveyed in 1931 — assesses shifts in community structure over the last 60 years (**Barry *et al*,** this volume). Of 45 species in the transect, the abundance of eight (out of nine) southern species increased and the abundance of five (out of eight) northern species decreased, a pattern consistent with poleward migration due to warming over the period. Measurements at the site also show that annual mean shoreline ocean temperatures increased 0.75°C, and mean summer maximum temperatures increased 2.2°C between 1921-1931 and 1983-1993.

Hydrology

The next series of contributions address hydrologic issues. At the 1994 PACLIM workshop, Maurice Roos of the California Department of Water Resources, in surveying recent years of precipitation, queried "Has the California Drought Returned?" (Roos, 1995). After 6 years of drought during 1987-1992, the 1993 water year ended the California drought with about 150% of average precipitation and good carryover reservoir capacity (Roos, 1994), but the low 1994 water year again placed California in a "drought watch" mode. The "drought watch" ended with two large rain months (January and March 1995), which made 1995 one of the wettest years of the century. **Roos** (this volume) describes the season in detail, the major storms, and the performance of reservoirs and flood control systems at near capacity.

Addressing the relationship between recent winters in the western United States and ENSO patterns, **Redmond** (this volume) points out the impact of recent droughts on water allocation throughout the west and salmon population in the Pacific Northwest. He describes a new tool — the Standardized Precipitation Index — to replace the Palmer Drought Index for evaluating climate elements on different time scales. His analysis suggests that the last four winters represent more or less constant El Niño conditions, and that resulting snowpack conditions have been consistent with patterns of the last 60 years.

In a longer view of Pacific Northwest precipitation and hydrologic response, **Vaccaro** (this volume) examines precipitation records for 50 sites and streamflow records for 112 sites throughout the period of instrumental data. Three different periods of persistent conditions were identified — pre-1947, 1947-1976, and post-1976. The base period (1947-1976) had consistently higher water-year precipitation and stream discharge than earlier or later periods, but the highest runoff-season precipitation was in the post-1976 period. Together, the data suggest a change in the hydrometeorological regime post-1976 with increased runoff-season precipitation over part of the Pacific Northwest and decreased water-year precipitation and streamflow over most of the region.

Because river salinity and soil salinization are major issues affecting water use throughout the western United States, the impact of climate on salinity is explored by **Peterson *et al*** (this volume). Overall, the effect of wetter climate is to increase river discharge and decrease soil and river salinity; the effect of dryer climate is the reverse. Applying statistical-dynamical methods to water quality surveys from the early 1900s to minimize the effects of human impact, the study shows that much variability in river salinity in the western United States can be characterized as a response to storm and annual discharge.

Hazards — Floods, Fires, and Ecosystem Disturbances

One of the most prominent hazards of short-term climate variability is flooding. Because of the episodic nature of floods, however, flood histories are rarely known well enough to predict the full range of likely magnitudes and frequencies. An excellent example of resulting unexpected havoc was the 1990 flood of Havasu Creek, an inhabited tributary of the Colorado River in the Grand Canyon (**Melis and Phillips,** this volume). Although perennial streamflow averages about 2 m^3/s, the 1990 flood peaked at about 575 m^3/s, scouring local trees, reshaping pools and waterfalls, and causing severe damage to a nearby town. Using historical accounts and photographs, Melis and Phillips reconstructed flood histories for the creek, finding that similar large floods occurred frequently in the late 19th and early 20th centuries. While floods in 1940-1990 were unusually small, the recent flood pattern more closely resembles the dynamic flood regime of the early 20th century.

Turning to flood histories in the more distant geologic past, **Byrne and Sullivan** (this volume) present preliminary results on paleoflood records for the past 800 years in the Sacramento Valley. The records derive from sediment cored in an oxbow lake, and identification of the flood deposits is based on x-radiograph density and magnetic susceptibility. Judged from chronologies derived from Pb210 and radiocarbon dates, calibration with the historical record over the past 150 years looks promising, and three major flood events are apparently recorded for the period 1440-1525 AD.

In a similar approach, **Byrne *et al*** (this volume) are studying varved lake sediments as a possible paleorecord of large tropical storms in the State of Jalisco, Mexico. Dense laminae 2-4 times thicker than typical layers are hypothesized to represent above-average erosion in the watershed during tropical storm events, and preliminary calibration with the historical record in the period 1921-1990 tentatively confirms the interpretation. If so, reconstruction suggests a total of about 10 large tropical storms in the area over the past 7,000 years.

Another major climate-related hazard — especially notable in urban areas of California — is debris flows, which can be triggered by severe rainstorms and result in sudden destruction of life and property. **Wilson** (this volume) describes the debris flow warning system operated jointly since 1986 by the U.S. Geological Survey and National Weather Service in the San Francisco Bay region. Based on a network of radiotelemetered rain gauges, the system is used to issue public advisories when local rainfall reaches critical levels. The value of the system was well demonstrated during the severe flooding of the winter of 1994-95.

Swetnam and Betancourt (this volume) argue that the most important climatically driven terrestrial ecosystem changes are annual- to decadal-scale episodic events manifested as regionally synchronized disturbance events, such as floods, fires, and insect outbreaks. In the Columbia River Basin, management planning for disturbance events focuses on blown-down trees, cold damage to infant plants, rain-on-snow floods, lightning fire ignition, drought stress, and frontal winds during fire season (**Ferguson and Peterson,** this volume). Analytic tools for management include pattern identification and simple algorithms using common indices, such as the Palmer Drought Severity Index and McKee's Precipitation Deficit Index.

On a longer time scale, **Anderson and Smith** (this volume) address fire history, natural biomass burning, and their relationship to climate over the past 9,000 years. Based on the integration of paleo-fire histories from tree-ring studies with paleo-vegetation sequences from sediments of montane meadows at several locations in the Sierra Nevada, preliminary results suggest that natural burning was high during the period about 9200-8700 YBP, low 8700-4500 YBP, and high again for the past 4500 years. This pattern is hypothesized to result from greater conifer forest development (and associated burning) due to Holocene climate changes.

Glaciers

Like river discharge, glaciers show complex responses to climate variability. **Hodge *et al*** (this volume) elegantly illustrate the impact of interdecadal variability on glacial conditions in a study of the South Cascades Glacier in Washington. Based on a 36-year time series, the study shows that the winter (and net) glacier balance underwent an abrupt step-like decrease in one year, between 1976 and 1977. The summer glacier balance shows no long-term trend, and changes in the winter balance are not associated with decreased total winter precipitation or with increased regional winter temperature, but with changes in conditions allowing snow to accumulate.

Extending Walters and Meier's (1989) evaluation to the longer time-series now available, **Walters** (this volume) employs empirical orthogonal function analysis to mass balance time series of seven western North America glaciers. Comparison of the results with climatological variables shows strong correlation with large-scale variations in seasonal 700-millibar height and sea level pressure and weaker correlations with the Southern Oscillation Index and the Pacific North American Index. The study concludes that the response of individual glaciers is more closely related to large-scale atmospheric conditions than to local-scale meteorological differences.

Putting the present century's climate variations in perspective, **Porter** (this volume) details glacial variations and climate during the Little Ice Age. Using a combination of historical data (paintings, maps, photographs, *etc*), dendrochronology, and studies of crustose lichens, Porter dates the onset of the Little Ice Age to the middle of the 13th century (AD 1250). For the next several centuries, glacial advances, expanding sea ice, crop failures, and famine resulted in much of Europe and the North Atlantic, with peak glacial advance in the early 1600s and glacial retreat beginning about the middle of the 19th century. Porter concludes that glacial fluctuations of the Little Ice Age were unrelated to orbital forcing and not obviously related to solar variations, but they closely resemble the succession of major sulfur-emitting volcanic eruptions.

Even at century scales, however, spatial variability is indicated by **Luckman's** (this volume) review of evidence from the terrestrial paleorecord of climate change over the last thousand years in the Canadian Rockies. Combining data from glaciers, glaciolacustrine sediments, dendrochronology, and tree-line fluctuations, Luckman suggests that most of the classic features of the European climate over the last millennium — the Medieval Warming and Little Ice Age — are not apparent in the Canadian Rockies. There, the broad pattern over the last millennium was progressively more extensive glacial advances, culminating in the 18th and 19th centuries.

Proxy Calibration

One of the major challenges in understanding the scale of natural variability in the climate system is extending instrumental time series by the construction of high-resolution proxy indicators. Tree-ring width, oxygen isotopes in corals, ice accumulation in glaciers, sediment varve thickness, and many other parameters have been discussed, compared, and integrated at previous PACLIM workshops (*eg*, Baumgartner *et al* 1989). As new techniques evolve and new time-series are developed in new locations, the calibration of proxy indicators must be continuously re-examined and re-evaluated.

The next series of contributions address proxy calibration using a variety of indicators in a number of different settings. **Weinheimer and Cayan** (this volume) report recent results on radiolarian assemblages in 20th century varved sediment from Santa Barbara Basin cores. Fluxes of total radiolarians, percent specimens with warm affinities, and percent specimens with cool affinities all reflect SST fairly well for 1950-1991 as previously reported (Weinheimer *et al* 1995), suggesting a promising proxy for paleo-SST in the California Current. However, although new data show that the same relationships apply to sediment deposited in the period 1914-1930, opposite relationships are observed in the period 1930-1950. Neither the varve chronology nor statistical analysis of the radiolarian assemblages points to a simple explanation of this mismatch, so future research will focus on further investigation of the relationships.

Also in the Santa Barbara Basin, **Baumgartner and Southon** (this volume) are developing a detailed series of ^{14}C ages of oceanic materials from samples of the pelagic pteropod *Limacina helicina*, which lives in the upper 100 meters of the water column. Preliminary calibration of terrestrial and marine ^{14}C ages over the period AD 1260-1900 exhibit differences at centennial scales interpreted as the result of variations in large-scale upwelling associated with changes in the intensity of the California Current. Other proxy indicators discussed from varved sediment records are planktic foraminifera fluxes and paleotemperature determinations based on the alkenone biomarker index U^{K}_{37} in Soledad Basin along the southern California Baja margin (**Herguera *et al***, this volume).

Coral records from Clipperton Atoll in the eastern Pacific, on the periphery of the influence of ENSO warm events, were developed by subsampling at 10-20 intervals per year (**Linsley and Dunbar**, this volume). Calibration of oxygen isotope ratios with existing instrumental and satellite-derived datasets show that the corals represent an apparently accurate record of SST in the region. Evaluation of a 120-year time series shows that SST has been stable for the past 120 years, except for a 0.5°C warming over the past 10 years consistent with SST data. **Jones *et al*** (this volume) evaluate oxygen isotope records from corals near the tip of Baja California and from the Gulf of Panama. Calibration of the Baja coral with temperature records shows that the coral data exhibit a strong annual temperature cycle but correlate poorly with temperature records at an annually averaged scale. The Panama coral data correlate strongly with salinity at a bimonthly scale and moderately at an annual scale but are not significantly related to temperature. Coherence between three records in the Panama region, however, show that the corals record regional signals.

The goal a study by **Biondi *et al*** (this volume) is the integration of terrestrial and oceanic records in southern California for reconstructing west coast climate. Using tree rings and marine laminated sediments,

large-scale ocean/atmosphere parameters (including precipitation, temperature, sea level pressure, and primary productivity) can be reconstructed in high-resolution time series. Comparing indicators of precipitation in a varve chronology from Santa Barbara Basin sediment cores with a newly developed tree-ring chronology for the Torrey pine, the study concludes that dark varve layer thickness relates mostly to local rainfall, while tree-ring indices reflect more regional precipitation.

Synoptic dendroclimatology is the subject of the contribution by **Hirschboeck *et al*** (this volume). Using connections between large-scale circulation and tree-ring-width variation at local sites, the authors compared tree-ring chronologies from central Oregon and northern New Mexico. Results show that high and low tree growth at the two sites is associated with totally different large-scale circulation patterns for the prior winter. In Oregon, growth is enhanced by lower-than-normal 500-millibar pressure heights over the Gulf of Alaska; in New Mexico, high growth years are correlated with a belt of lower-than-normal 500-millibar pressure heights extending across the North Pacific into the Southwest. For the Sierra Nevada, **Garfin** (this volume) also examines the relationship between tree growth and large-scale circulation patterns.

Pollen and Lake Records

The next set of contributions looks at longer, lower-resolution time-series illuminating ecosystem and lake histories extending as far back as 800,000 years.

The first paper reports a multidisciplinary approach to quantitatively linking climate changes with the hydrologic cycle, with the goal of providing tools for future forecasting of regional hydrologic responses to climate change (**Smith *et al***, this volume). The study is focused on Elk Lake in Minnesota, a lake with a well-documented record of mid-Holocene climate change characterized by lower precipitation, higher summer insolation, and lower lake levels. The region also has a known history of drought during the 1930s, which can be used to calibrate the mid-Holocene record to reconstruct climate-driven hydrologic transients and thereby obtain estimates of past hydrologic conditions. The paper discusses modeling of present lake/ground water interaction, and analysis of mid-Holocene cores for ostracode assemblages, trace metals, and oxygen isotopes.

Benson *et al* (this volume) examine oxygen isotopic ratios in sediment cores from Owens Lake in eastern California to evaluate their linkage with North Atlantic climate events such as the Younger Dryas and Heinrich events (circa 50, 33, 27, 20.6, 14.6, and 11-10 ka). Detailed reconstruction of the Owens Lake chronology shows that the lake was hydrologically open (overflowing) most of the time between 52.5 and

12.5 ka, but desiccated between about 15.5 and 13.7 ka. Evaluation of the oxygen isotope record suggests that most oscillations in the hydrologic balance of Owens Lake do not strongly correspond to climate oscillations recorded in the North Atlantic.

Also from Owens Lake but covering a longer period, the diatom record suggests a shallow open-water environment from 800-440 ka and a deeper basin environment thereafter, with short intervals of shallow saline conditions (**Bradbury**, this volume). Calibration of the lake chronology with oxygen isotope stages recorded in marine deposits indicates a good correlation, with glacial conditions represented by diatom assemblages dominated by freshwater planktic species, indicating abundant Sierra Nevada precipitation.

Pollen records in the western United States are discussed in two contributions. **Wigand and Hemphill** (this volume) present preliminary analyses of a 5-meter core from Lower Pahranagat Lake in southern Nevada. Spanning the past 2,000 years, long-term trends in the pollen record illustrate the increasing dominance of steppe and desert scrub species compared to grasses in southern Nevada. Further work is planned, including analysis of ostracods and pollen analysis of additional core recently recovered with a basal data of 5.6 ka. On a longer timescale, **Whitlock and Bartlein** (this volume) examine pollen records extending back to 75 ka from Carp Lake and Little Lake in Oregon.

Proxy records from Lake Estancia in New Mexico (32-12 ka) are discussed in another pair of contributions. **Allen *et al*** (this volume) report preliminary results from a number of sedimentologic and proxy indicators (including stable isotopes and trace-metal ratios of ostracods) suggesting that climatic conditions in the area shifted episodically (and rapidly) toward drier and then wetter conditions. The fluctuations in climate indicate that dramatic changes in the transport of Pacific moisture occurred during the last Ice Age. To correlate the climate record from Lake Estancia with records from the Pacific and west coast of North America, **Rowe *et al*** (this volume) are conducting a study of rock-magnetic and geomagnetic secular variation in the same sequence.

Time-Series Compilations

The last two contributions compile and compare numerous datasets from a wide variety of sources. **Karlstrom** (this volume) refines his earlier analysis of time series based on the forcing function of the 556-year maximum tidal force (Karlstrom 1995) to focus on the 2-2.5 year quasi-biennial oscillation (QBO). The paper focuses on the QBO in stratospheric winds and correlations with the El Niño/Southern Oscillation, suggesting that one or both of these oscillations is modulated or amplified by the same tidal-resonance system.

Finally, **Sharp** (this volume) focuses on understanding societal and ecosystem responses to climate regime shifts. Collating regional and global warm and cold events with records of documented ecosystem response and health threat for the historical period, the presentation associates climate shifts with stimulation of disease vectors and considerable human health impacts.

References

Baumgartner, T.R., J. Michaelsen, L.G. Thompson, G.T. Shen, A. Soutar, and R.E. Casey. 1989. The recording of interannual climatic change by high-resolution natural systems: Tree-rings, coral bands, glacial ice layers, and marine varves. Pages 1-14 in *Aspects of Climate Variability in the Pacific and the Western Americas*. D.H. Peterson, editor. Geophysical Monograph 55, American Geophysical Union, Washington, D.C.

Ebbesmeyer, C.C., D.R. Cayan, D.R. McLain, F.H. Nichols, D.H. Peterson, and K.T. Redmond. 1991. 1976 step in the Pacific climate: Forty environmental changes between 1968-1975 and 1977-1984. Pages 115-126 in *Proceedings of the Seventh Annual Pacific Climate (PACLIM) Workshop, April 1990*. J.L. Betancourt and V.L. Tharp, editors. California Department of Water Resources, Interagency Ecological Studies Program Technical Report 26.

Karlstrom, T. 1995. A 139-year dendroclimatic cycle, cultural/environmental history, sunspots, and longer-term cycles. Pages 137-159 in *Proceedings of the Eleventh Annual Pacific Climate (PACLIM) Workshop, April 19-22, 1994*. C.M. Isaacs and V.L. Tharp, editors. California Department of Water Resources, Interagency Ecological Studies Program Technical Report 40.

Roos, M. 1994. Is the California drought over? Pages 123-128 in *Proceedings of the Tenth Annual Pacific Climate (PACLIM) Workshop, April 4-7, 1993*. K.T. Redmond and V.L. Tharp, editors. California Department of Water Resources, Interagency Ecological Studies Program Technical Report 36.

Roos, M. 1995. Has the California drought returned? Pages 181-183 in *Proceedings of the Eleventh Annual Pacific Climate (PACLIM) Workshop, April 19-22, 1994*. C.M. Isaacs and V.L. Tharp, editors. California Department of Water Resources, Interagency Ecological Studies Program Technical Report 40.

Schimmelmann, A., and M.J. Tegner. 1992. Historical evidence of abrupt coastal climatic change in Southern California, 1790-1880. Pages 47-56 in *Proceedings of the Eighth Annual Pacific Climate (PACLIM) Workshop, March 10-13, 1991*. K.T. Redmond, editor. California Department of Water Resources, Interagency Ecological Studies Program Technical Report 31.

Schwing, F.B. 1994. Long-term and seasonal patterns in coastal temperature and salinity along the North American west coast. Pages 129-143 in *Proceedings of the Tenth Annual Pacific Climate (PACLIM) Workshop, April 4-7, 1993*. K.T. Redmond and V.L. Tharp, editors. California Department of Water Resources, Interagency Ecological Studies Program Technical Report 36.

Thompson, L.G. 1991. Initial global perspective of climate for the last thousand years: The ice core record. Pages 147-151 in *Proceedings of the Seventh Annual Pacific Climate (PACLIM) Workshop, April 1990*. J.L. Betancourt and V.L. Tharp, editors. California Department of Water Resources, Interagency Ecological Studies Program Technical Report 26.

Thompson, L.G., and E. Mosley-Thompson. 1989. One-half millennia of tropical climate variability as recorded in the stratigraphy of the Quelccaya ice cap, Peru. Pages 15-31 in *Aspects of Climate Variability in the Pacific and the Western Americas*. D.H. Peterson, editor. Geophysical Monograph 55, American Geophysical Union, Washington, D.C.

Walters, R.A., and M.F. Meier. 1989. Variability of glacier mass balances in western North America. Pages 365-374 in *Aspects of Climate Variability in the Pacific and the Western Americas*. D.H. Peterson, editor. Geophysical Monograph 55, American Geophysical Union, Washington, D.C.

Weinheimer, A.L., and D.R. Cayan. 1995. Radiolarian flux in the Santa Barbara Basin as an index of climate variability. Pages 107-118 in *Proceedings of the Eleventh Annual Pacific Climate (PACLIM) Workshop, April 19-22, 1994*. C.M. Isaacs and V.L. Tharp, editors. California Department of Water Resources, Interagency Ecological Studies Program Technical Report 40.